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URBAN AIR SHED PHOTOCHEMICAL SIMULATION MODEL STUDY

VOLUME I. DEVELOPMENT AND EVALUATION. APPENDIX C. MICROSCALE MODEL OF LOCAL VEHICULAR SOURCE CONTRIBUTIONS TO MEASURED POLLUTANT CONCENTRATIONS

SYSTEMS APPLICATIONS, INCORPORATED

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The aims were the development and validation of a simple diffusion model for CO to investigate the feasibility of modeling at two spatial scales. Limited results are reported for four LA County stations. While the main purpose of developing a microscale model was to provide a realistic basis for validating an urban scale model, the microscale model (or "micromodel") may well be useful in other contexts. Previous efforts in measuring and predicting local variations in concentrations due to nearby sources were reviewed. Then the microscale model is presented. The authors give a general description of the model, discuss details of its formulation for application in the vicinity of low structures (one to two story buildings) and present graphs displaying the relationship between the magnitude of concentration elevation and the distance of the sampling probe from the street, the speed and direction of the local wind, and the magnitude of the local turbulent eddy diffusivity. They then present the results of applying the model in the prediction of hourly carbon monoxide concentrations at the Lennox, West Los Angeles, Whittier and Long Beach monitoring stations for six validation days.

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VOLUME I - DEVELOPMENT AND EVALUATION

Appendix C - Microscale Model of Local Vehicular Source Contributions to Measured Pollutant Concentrations

by

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I. INTRODUCTION

One of the important considerations in the development of an urban airshed model is the selection of an appropriate spatial scale. The choice of scale is influenced by a number of factors, including:

- The degree of detail with which emissions patterns are known.
- The density of the meteorological data collection network, and thus the spatial resolution of the measured windfield.
- The increases in computing time and storage requirements that are associated with increasing fineness of spatial resolution.
- The relationship between spatial and temporal scales.

As a result, scale selection frequently represents an attempt to effect a compromise between degree of detail incorporated and magnitude of computing requirements.*

While the selection of a particular grid size is required for solution of the governing equations of the model, the consequences of having to make such a choice are often unsatisfactory. There are three principal sources of difficulty.

- The impossibility of describing turbulent transfer processes using one scale of resolution when these processes occur over a broad range of scales, from the very coarse (movement of large air masses) to the very fine (the smallest of eddies). Large eddies derive their energy from the main stream of flow and are relatively unstable. They tend to break down into eddies of smaller size, which in turn fragment in still smaller eddies. This cascading process continues until the scale characterized by molecular viscosity is reached. The theoretical treatment of this continuous spectrum of energy (or eddy sizes) is extremely complex. The adoption of K-theory has permitted the development of semi-empirical models of turbulent processes, but has not dealt with the problem of the spectrum of scales.
- The inability to account for the effects of sub-grid scale variations in source emissions (and thus contaminant concentrations), such as occur in the vicinity of major roadways, strong point sources, and large airports. These variations are properly characterized on a

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* In the application of our model to the Los Angeles Basin, we have adopted a square grid network of 625 2 x 2 mile grid squares.

scale that is small (or fine) compared with the scale adopted for use in urban airshed modeling. Such variations will not be taken into account, for example, on the 2 x 2 mile grid used in the SAI model.

- The inability to account for the effects of sub-grid scale variations in surface features, such as buildings and elevated freeway structures. Such structures alter local wind patterns and turbulence levels, which contribute to the establishment of local concentration levels. Similarly, the presence of high-rise buildings along the street borders, the so-called "street canyon", can reduce considerably the influence of "main stream" convective transport processes on the dilution of street level emissions. These effects occur on a scale that is small compared with that typically adopted in urban modeling and are thus "lost in the shuffle".

These deficiencies are of particular concern when one wishes to validate an airshed model by comparing its predictions with point measurements of contaminant concentrations.

Consider the validation of an urban airshed model, where carbon monoxide is the pollutant of concern.* The model is based on the assumption that emissions are uniformly distributed in space and time (over an hourly interval) over each 2 x 2 mile cell and that meteorological conditions are also invariant over this scale. The direct result of these assumptions is that *the predicted pollutant concentrations* are uniform within each grid square (or cell). *The observed values* of CO, however, typically are representative only of the CO concentrations in the immediate vicinity of the monitoring station. Of the nine monitoring stations operated by the Los Angeles County APCD, seven are located within 100 feet of a roadway having a daily traffic count in excess of 15,000 vehicles. Ott (1971) has shown that CO concentrations measured at a monitoring station situated along a busy city street are approximately twice the background level (400 feet or more away from the street) and slightly more than half that measured at the sidewalk located between the street and the station. While we may expect that a properly formulated urban scale model will predict background levels with reasonable accuracy on a 2 x 2 mile scale, there is no justification for comparing these predictions with local point observations. Some basis for comparison is required,

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* We assume for the purposes of this discussion that CO is unreactive.

however, if the validity of the model is to be established. Either background observations may be made, or a model may be developed that is capable of predicting concentrations at a nearby point that are due to local emissions. Since a measurement program is beyond the scope of this contract, and since we are limited to validation for six days in 1969, only the second of the two possibilities was open to us.

As we have noted, the main source of CO emissions in the vicinity of Los Angeles County air pollution monitoring stations is the automobile. Thus, to establish a basis for validation, we foresaw the need for a sub-grid, or microscale, model capable of predicting the elevation in concentration at the monitoring station, above background levels, that is contributed by local automotive emissions. The sum of this predicted concentration and the background concentration predicted using the urban scale model can then be compared with observed concentrations for the purpose of validation. We undertook the development and validation of a simple diffusion model for CO to investigate the feasibility of modeling at two spatial scales. We obtained limited results for four LA County stations, which we report herein. However, much remains to be done, both for CO and for the more complex situation in which chemical reactions take place, as in the case of NO and hydrocarbons.

While the main purpose of developing a microscale model was to provide a realistic basis for validating an urban scale model, the microscale model (or "micromodel") may well be useful in other contexts. The coarse resolution of the urban scale model does not suggest its use in the prediction of dosage in areas of substantial local variation in concentrations, such as along the sidewalk, in street canyons, and in areas of public access at airports. The "micromodel" may be of considerable value in estimating dosages in such situations, when used in concert with the urban scale model. The micromodel may also be of value in establishing a basis for formulating air quality standards. As concentrations can vary substantially in the vicinity of strong sources, perhaps air quality standards should be based on obtaining measurements at locations of greatest exposure--along sidewalks, within the automobile, inside the school yard. To properly establish such standards, based on historical measurements, one must rely on a model capable of describing local variations.

In this report, we review previous efforts in measuring and predicting local variations in concentrations due to nearby sources (Section II). We then present the microscale model developed in this study (Section III). We give a general description of the model, discuss details of its formulation for application in the vicinity of low structures (one to two story buildings) and present graphs displaying

the relationship between the magnitude of concentration elevation and the distance of the sampling probe from the street, the speed and direction of the local wind, and the magnitude of the local turbulent eddy diffusivity. We then present the results of applying the model in the prediction of hourly carbon monoxide concentrations at the Lennox, West Los Angeles, Whittier and Long Beach monitoring stations for the six validation days (Section IV). Finally, we make recommendations as to future needs in the continued development of microscale models (Section V).

II. SURVEY OF PREVIOUS STUDIES

Because emissions from automobiles constitute a major contribution to the total atmospheric pollutant load in urban areas, a number of studies have been undertaken in recent years that have been concerned with the dispersion of air contaminants in the vicinity of city streets. We summarize some of the important findings of these investigations in this section.

Carbon monoxide concentrations at "curbside" locations were measured by McCormick and Xintaras (1962) in Nashville, Tennessee and Cincinnati, Ohio. They found that the temporal variation in carbon monoxide concentration at both sites were correlated with hourly traffic counts made at the street along which the concentrations were measured, thus confirming the conclusions of an earlier study by Brief (1960). Furthermore, they noted that meteorological conditions, such as wind speed, wind direction, turbulence level and atmospheric stability, also played an important role in determining the level of carbon monoxide concentrations.

An extensive investigation was later carried out in Germany by Georgii and his co-workers (1967, 1969). Carbon monoxide concentrations, traffic density, and pertinent meteorological variables were measured at three sites located near three major streets in downtown Frankfurt/Main. (Traffic counts on the streets ranged between 1200 and 1800 cars per hour during peak hours.) Their findings are briefly summarized as follows:

A. Good correlation was established between the diurnal carbon monoxide concentration and the temporal variation in traffic density. Specifically, they found that the mean CO concentration c increases exponentially with the traffic density n, as given by

$$c = Ae^{an} \qquad (1)$$

Different values of a and A were used to describe the concentration along the windward and leeward sides of the street. That Georgii selected a functional relationship of exponential form is attributable to the fact that as traffic density increases, the average speed will decrease, which in turn, will result in an increase in emission rates.

B. One of two distinct local flow regimes will be established within a street canyon. Which regime persists is dependent upon whether the rooftop wind speed exceeds, is less than, or is greater than 2 meters per second (or 4.5 mph), as shown schematically in Figure 1.

C. The decrease in the mean CO concentration with rooftop wind speed, U, can be approximated by the following equation:

$$c = KU^{-p} \tag{2a}$$

where K and p are both empirically determined constants.

D. Carbon monoxide concentration within a street canyon varies exponentially with height z, as given by

$$c = Be^{-bz} \tag{2b}$$

However, different value of b and B are required for the windward and leeward sides.

The results of Georgii, et al. are generally confirmed by Schnelle, et al. (1969) and Johnson, et al. (1972). In particular, Johnson, et al. have proposed the following composite equation to describe the concentrations in a street canyon:

$$c_w = c_b + \frac{0.1\ K\ N\ S^{-3/4}}{W(U + 0.5)} \tag{3a}$$

$$c_\ell = c_b + \frac{0.1\ K\ N\ S^{-3/4}}{(U + 0.5)\left[(x^2 + z^2)^{1/2} + 2\right]} \tag{3b}$$

where

c_w windward side concentration

c_ℓ leeward side concentration

c_b background concentration

K dimensionless constant (=7)

N traffic density (vehicles/hr)

S average vehicle speed (miles/hr)

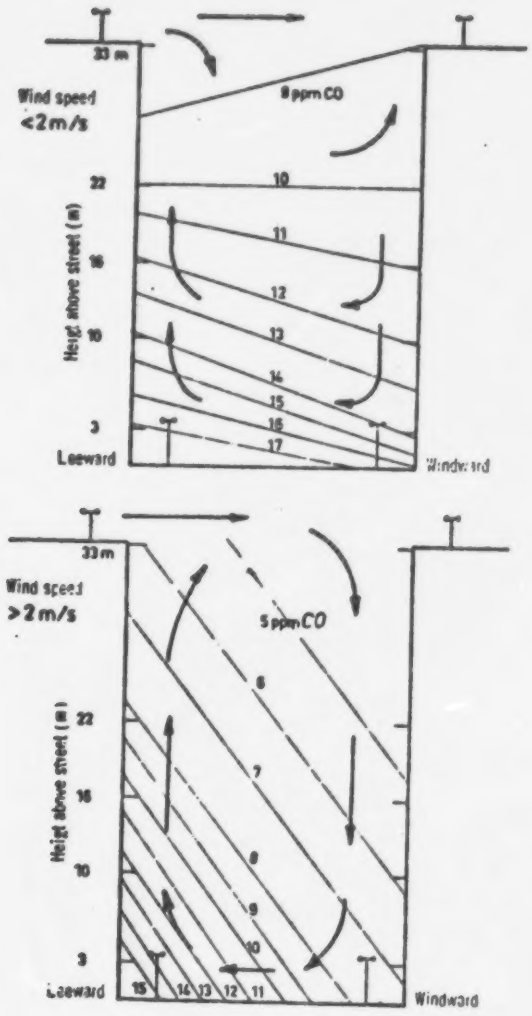


FIGURE 1. Air Circulation Within Streets at Different Wind Speeds (Georgii, 1969)

U rooftop wind speed (m/sec)

w width of the street (m)

x horizontal distance to the receptor point (m)

z vertical distance to the receptor point (m)

Although the numerical coefficients were obtained from an extensive measurement program carried out in San Jose, these formulae also correlated well with Georgii's data. Unfortunately, due to the limited number of parameters included, as pointed by Johnson et al. (1971), they failed to apply when the CAMP data were used. Nevertheless this work still represents the most comprehensive study on the effect of street canyon undertaken thus far.

The studies cited above, in general, have involved attempts to establish empirical or correlational relationships between concentration and meteorological and spatial variables. We have not attempted to review pertinent numerical modeling efforts, as we consider these to be too complex for this particular application. Readers interested in this area are referred to papers presented at the Air Pollution & Diffusion Symposium, Las Cruces, New Mexico (1971) by R.S. Hotchkiss, by D. Djurić et. al. and by P.C. Chang et. al. In the next section, we describe a simple but somewhat more fundamentally based modeling approach to predicting local pollutant concentrations and their variations.

III. THE MICROSCALE MODEL

No single model will suffice for describing transport and dispersion phenomena in the vicinity of a street, largely because distinctly different flow patterns can occur above the roadway surface. In the first part of this section we identify two flow patterns that are often observed and suggest a criterion for distinguishing between them. In the second part, we present a model for one of the two flow regimes, give the solution of the governing equations, and illustrate their application in a typical situation.

A. Identifying the Flow Regime

For the purpose of describing the dispersion of atmospheric contaminants in an urban environment, we first distinguish between the two circulation patterns that generally exist in the vicinity of a city block, as illustrated in Figure 2.

1. Free Flow Regime

Air at street level is directly ventilated by the prevailing wind at the rooftop. This case may be characterized by the fact that the directions of the street-level wind and the rooftop wind are the same.

2. Street Canyon

Air at street level does not have direct access to the prevailing wind. Instead, a vortex of direction opposite to that of the rooftop wind will be generated.

For modeling purposes we must be able to determine which of these regimes obtains for a particular set of meteorological conditions.

In order to develop a criterion to aid in identification of the appropriate regime, we consider the following very simple situation--a constant wind leaving the edge of a building as shown in Figure 3. Writing the two-dimensional, steady-state continuity and momentum equations for this situation, we have

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 \tag{4a}$$

$$u \frac{\partial u}{\partial x} + w \frac{\partial u}{\partial z} = K_M \frac{\partial^2 u}{\partial z^2} \tag{4b}$$

where K_M is the turbulent diffusivity of momentum.

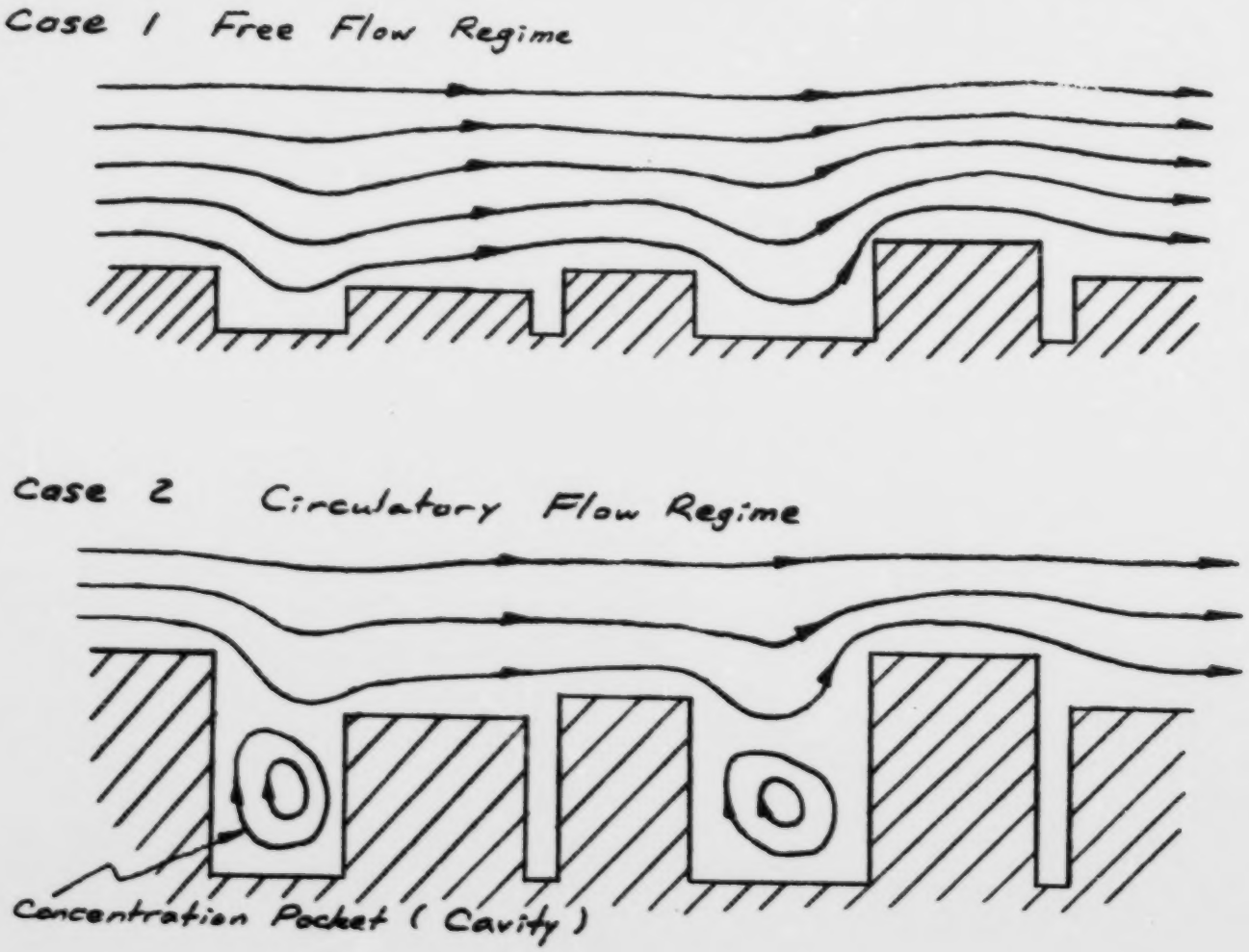


FIGURE 2. Typical Flow Patterns

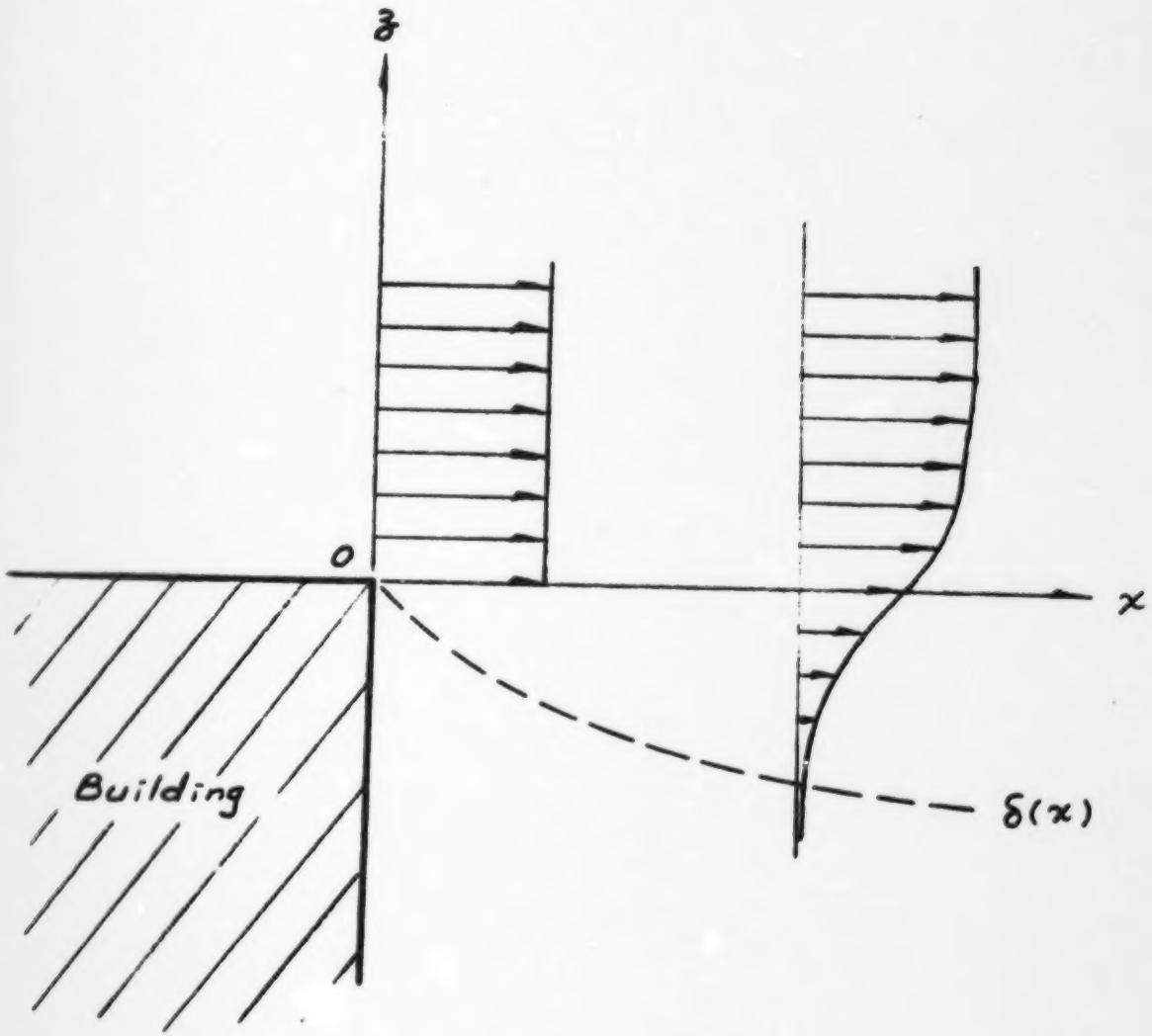


FIGURE 3. Flow Pattern at the Leeward Edge of a Building

The boundary conditions are:

$$u = \begin{cases} U & 0 < z < \infty \\ 0 & -\infty < z < 0 \end{cases} \qquad \text{at} \quad x = 0$$

$$u = U \quad \text{for } x > 0 \qquad \text{as} \quad z \to \infty$$

$$u = 0 \quad \text{for } x > 0 \qquad \text{as} \quad z \to -\infty$$

The solution to this boundary layer problem, given by Lock (1951), is shown in Figure 4. If we define a depth of penetration of the rooftop wind, δ, by choosing a corresponding u such that,

$$1 - \frac{u}{U} = 99\%$$

then from Figure 4, we obtain

$$\delta \simeq 7\sqrt{\frac{K_M x}{U}} \tag{5}$$

We can now employ equation (5) as a criterion in identifying the appropriate wind regime. If δ, the estimated depth of penetration of the rooftop wind, exceeds the average height of the upwind buildings, W, then street level air has access to the main stream and Case 1 applies. However, if $\delta < W$, Case 2 applies. Consider as an example two streets described by Georgii, et al. (1967):

Street	height (in meters)	width (in meters)
Karlstrasse	35.0	22.5
Stiftstrasse	25.7	17.5

Let us interpret x in equation (5) as street width. If we assume a street width of 20 meters (the average width of the two streets), a diffusivity K_M of 10^4 cm^2/second, and a mean wind of 2 meters/second, then

$$\delta = 7\sqrt{\frac{10^4 \times 2 \times 10^3}{200}} \text{ cm} = 31.4 \text{ meters}$$

Thus, $\delta > W$ for Stiftstrasse and Case 1 applies, whereas $\delta < W$ for Karlstrasse and Case 2 applies.

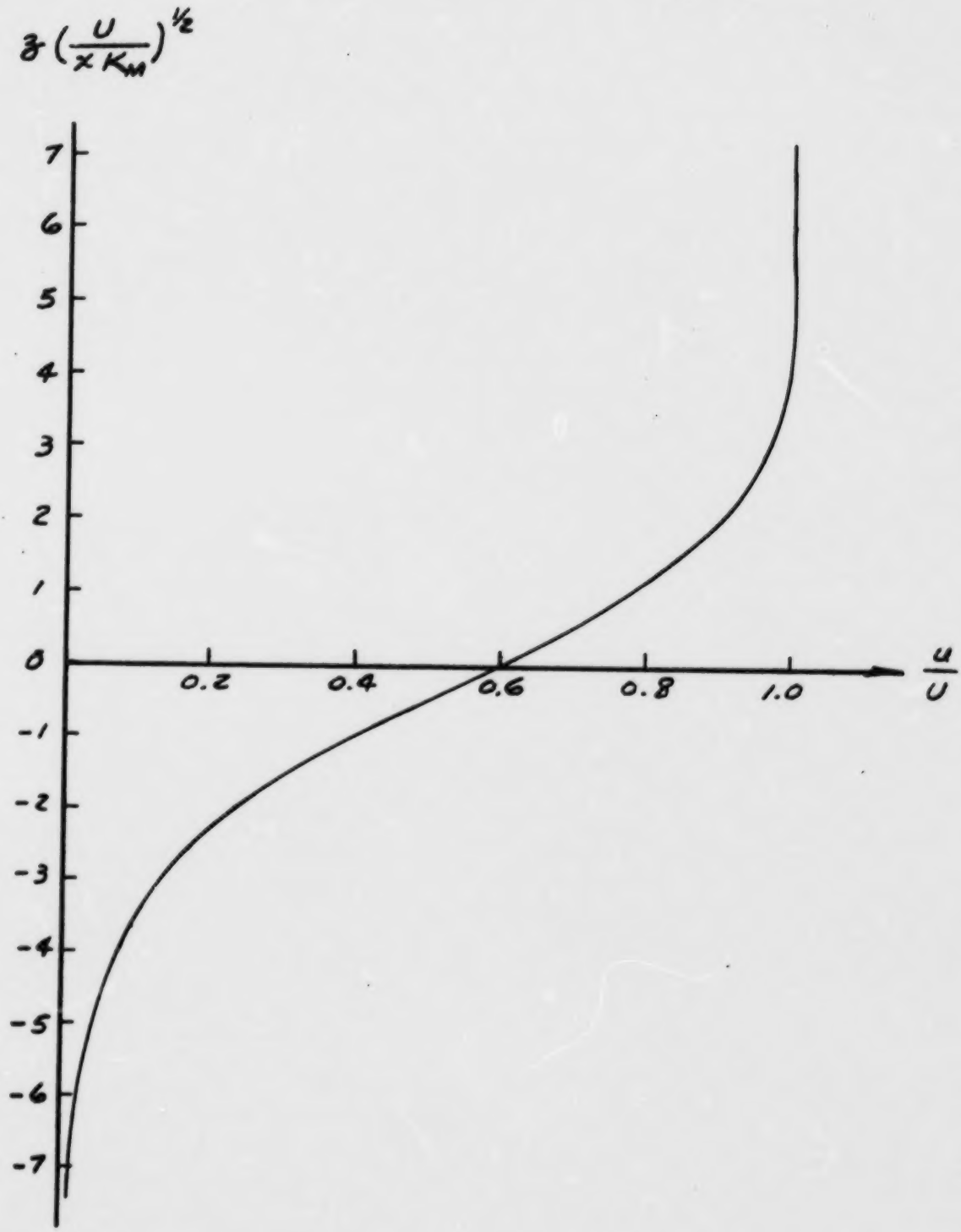


FIGURE 4. Calculated Velocity Profile Downwind of the Rooftop of a Building (Lock, 1951)

B. The Governing Equations and Their Solution

All nine Los Angeles County monitoring stations are located along a city street. In some instances the adjacent street is lightly traveled, as at Azusa and Reseda. More frequently, however, it is heavily traveled. With the exception of the downtown station, however, all are situated within, adjacent to, and in the vicinity of structures that are no more than one or two stories high. In such situations $\delta > W$ for all meteorological conditions except that of extremely light winds (less than 1/4 meter/second). We have thus restricted our efforts in this very limited study to the development of a model for Case 1, the free flow regime. In order to compute the contributions of local emitters to concentrations measured at the downtown station, it would necessary to develop a model describing the Case 2 flow regime; we have not attempted to do this in the present study.

We have made a number of assumptions in formulating a local scale transport and dispersion model for Case 1 flows. Most notable among them are the assumptions of

- steady state
- transport restricted to two dimensions
- averaged, instead of instantaneous, concentrations and velocities
- K-theory
- a line source
- constant horizontal wind speed and direction
- constant vertical diffusivity, invariant with height at a given time
- vertical diffusivity equal to horizontal diffusivity

A detailed derivation of the governing equations, together with an evaluation of these assumptions and their effect on predictions, is given by Seinfeld, et al. (1972).

Under the stated assumptions we can write the continuity equation as

$$U \frac{\partial c}{\partial x} = K_c \left[\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2}{\partial z^2} \right] \tag{6}$$

where

$$-K_c \frac{\partial c}{\partial z} = \begin{cases} Q & \text{at} \quad z = 0, \quad x = 0 \\ 0 & \text{at} \quad z = 0, \quad x \neq 0 \\ 0 & \text{as} \quad z \to \infty \text{ for all } x \\ 0 & \text{as} \quad x \to \infty \text{ for all } z \end{cases}$$

In contrast to the treatment of the velocity distributions, as prescribed by equation (4). We have in this instance retained the diffusion term in the flow direction, primarily because of the steep concentration gradients that are frequently observed in the vicinity of strong line sources.

The solution is given by Carslaw and Jaeger (1959) as

$$c = \frac{Q}{2\pi K_c} e^{Ux/2K_c} K_o \left[U(x^2 + z^2)^{1/2}/2K_c \right] , \qquad (7)$$

where K_o is the modified Bessel function of the second kind of order zero. The ground concentration ($z = 0$) is given by

$$c_{z=0} = \frac{Q}{2\pi K_c} \phi(\xi) \qquad (8)$$

where

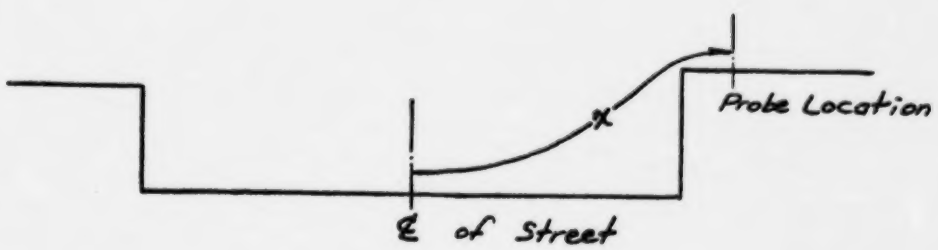
$$\phi(\xi) = e^{\xi} K_o(|\xi|)$$

and

$$\xi = \frac{Ux}{2K_c} .$$

The function $\phi(\xi)$ is plotted in Figure 5.

In applying equation (8), we take x to be a coordinate oriented parallel to the direction of the wind. Thus, distances are measured from the intake port of the monitoring station along the coordinate axis (which passes through the location of the intake port) to the intersection of the axis with the centerline of the street. Also, x is measured along a streamline that passes over the street near the surface, in the free flow regime. Thus,



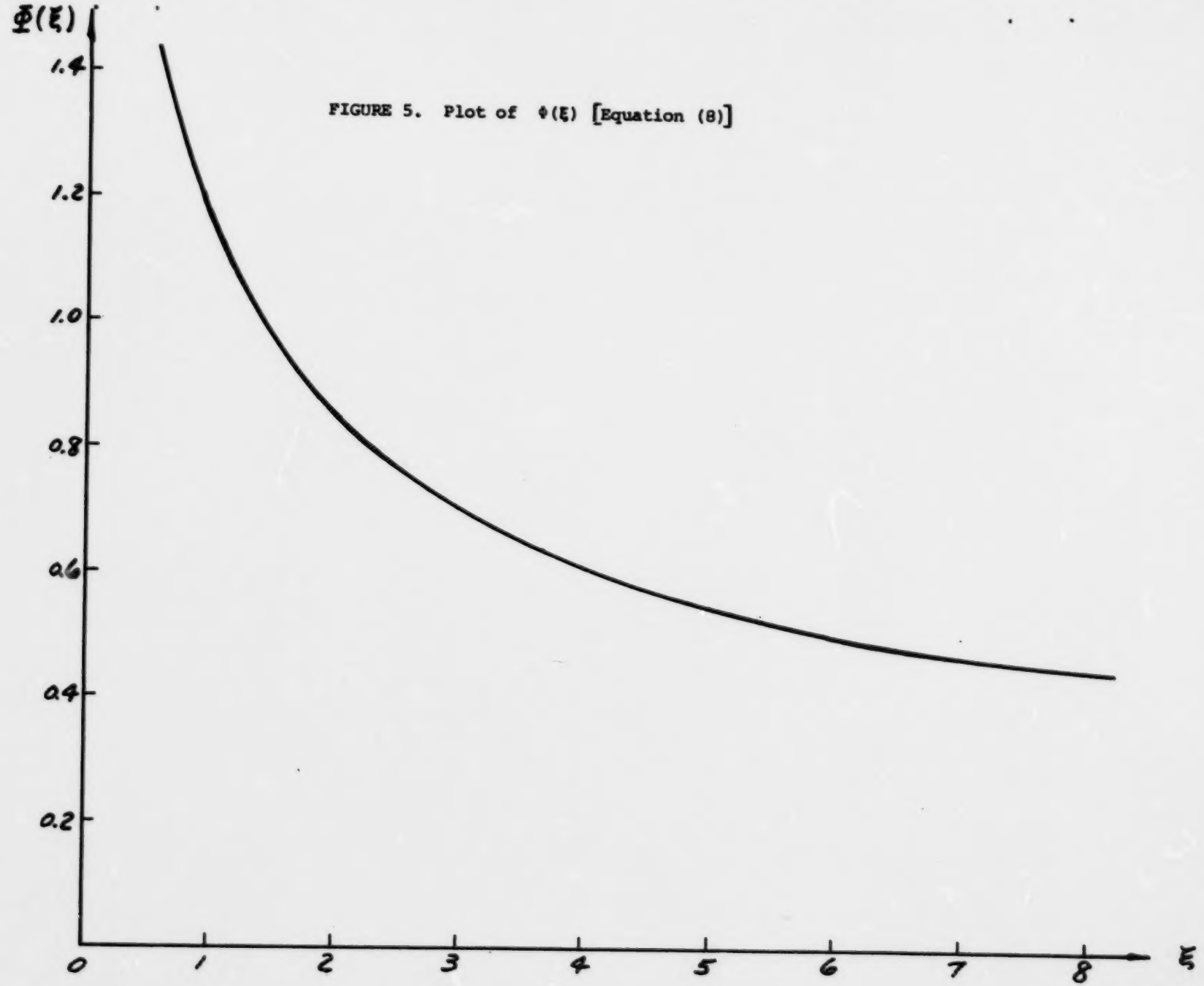


FIGURE 5. Plot of $\Phi(\xi)$ [Equation (8)]

As we have noted the solution of equation (6) is based on the assumption of a constant vertical diffusivity, invariant with height. Because we are examining a region adjacent to the surface of very shallow depth, and in which mixing is vigorous due to the flow, this assumption is probably fairly good. However, during the period over which the change in surface temperature with time is large--the morning hours following sunrise--the changes in diffusivity with time are also substantial. To account for these changes, we have assumed that K_c changes with time in a manner shown in Figure 6. The functional relationship, as well as the magnitude of K_c (note that the plot is semilogarithmic), is based on the research results of Staley (1956). While we are aware that the values of K_c are subject to considerable uncertainty, the relationship shown also corresponds with the findings of other investigations, for example, Jehn and Gerhardt (1950).

To illustrate the use of equation (8), consider the case of a 1 meter/second (or 2.25 mph) wind blowing from east to west, perpendicular to the San Diego Freeway. This highway has a traffic volume of about 26,000 vehicles/hour at 6 A.M. Assuming that carbon monoxide is emitted at a rate of 25.6 grams/mile (at 60 mph), the line source strength, in ppm-ft^2/minute, is

$$26{,}000 \frac{\text{vehicles}}{\text{hour}} \times 25.6 \frac{\text{grams}}{\text{mile vehicle}} \times .089 \frac{\text{ppm-ft}^2/\text{minutes}}{\text{grams/hour mile}}$$

The distance from the freeway to the intake port at the Lennox monitoring station is approximately 150 meters (or about 500 feet). If we assume that $K_c = 5 \times 10^3$ cm^2/second (= 323 ft^2/minute), then

$$c = \frac{26{,}000 \times 25.6 \times .089}{2\pi \times 323} \Phi(150)$$

$$\approx 2.9 \text{ ppm} \quad .$$

If the wind were from the northeast, bringing contaminants emitted along Imperial Highway and the San Diego Freeway to the station, then the concentration increase is estimated by superposition of the individual contributions of the two sources. Thus, if

$$U = 1 \text{ meter/second}$$

$$K_c = 5 \times 10^3 \text{ cm}^2/\text{second}$$

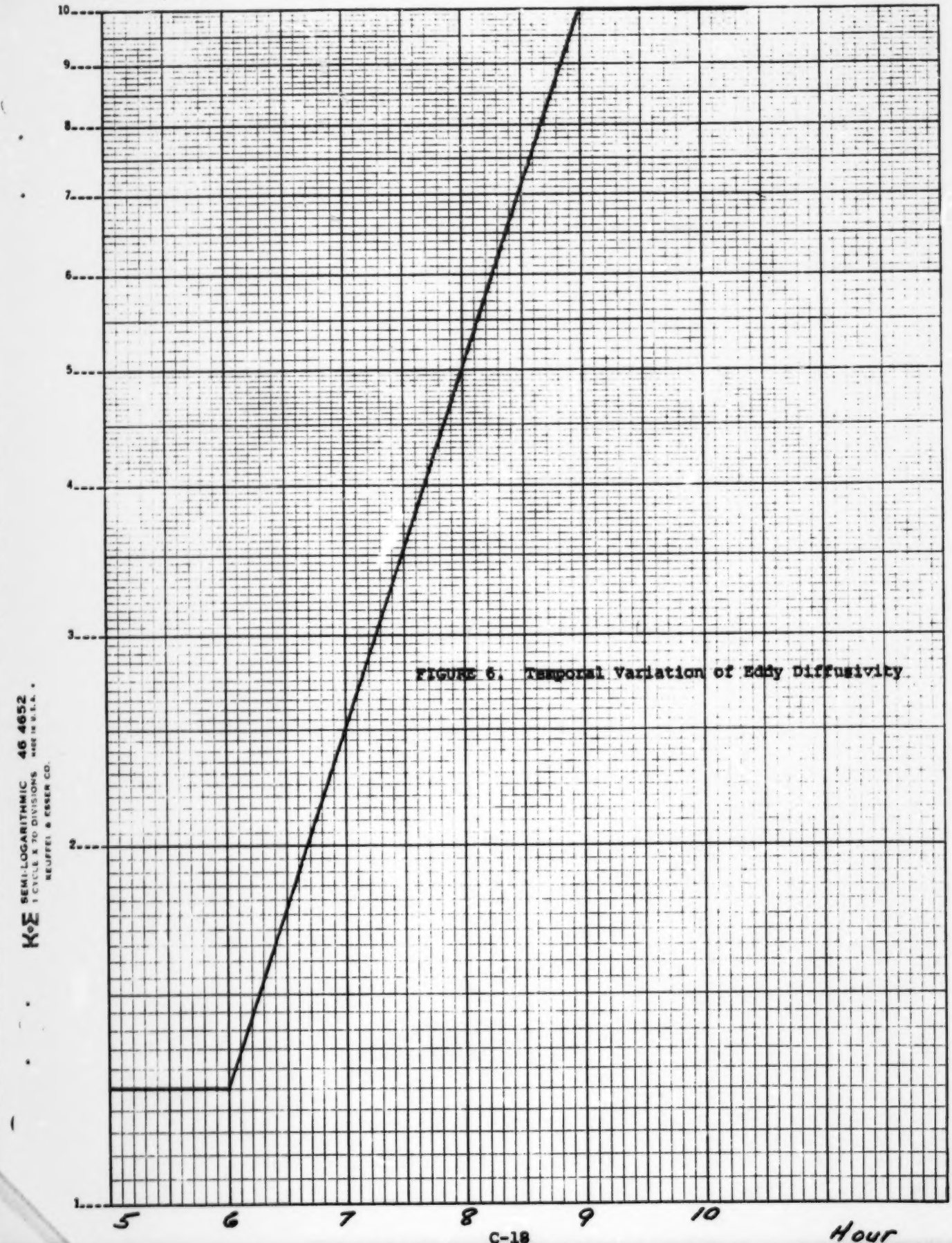


FIGURE 6. Temporal Variation of Eddy Diffusivity

and

	Imperial Highway	San Diego Freeway
Q(vehicles/hour)	4000	26,000
x(meters)	25 csc 45°	150 csc 45°

then

$$c \cong c_{\text{SD Freeway}} + c_{\text{Imperial}}$$

$$\cong 2.1 \text{ ppm} + 2.4 \text{ ppm}$$

$$\cong 4.5 \text{ ppm}$$

An emissions rate of 68.6 grams/mile of carbon monoxide is assumed for the calculation of the Imperial Highway contribution.

One cause of concern to us was the assumption of emissions being concentrated along the centerline of the street, in effect treating the street as a source of infinitesimal width. In reality typical distances of interest from centerline to sampling port are of the order of 10 to 40 meters. Street widths are of the magnitude of these transport distances, varying from 8 to 30 meters. In order to assess the effect of the line source assumption on predicted concentrations, we compared the solution of equation (6) with the solution of the continuity equations for emissions from a street of finite width. The major change in the governing equation in the latter case, when compared with equation (6), is in the boundary conditions,

$$-K_c \frac{\partial c}{\partial z} = \begin{cases} Q/2\ell & \text{at} \quad z = 0 \quad \text{for} \quad -\ell < x < \ell \\ 0 & \text{at} \quad z = 0 \quad \text{for} \quad |x| > \ell \end{cases}$$

The remaining boundary conditions are unchanged.

The solution of the governing equation for the finite width case is given by

$$c_{z=0} = \frac{Q}{2\ell\pi U} \int_{\frac{U(x-\ell)}{2K_c}}^{\frac{U(x+\ell)}{2K_c}} e^{\xi} K_o(\xi)\, d\xi \qquad |x| \geq \ell \qquad (9)$$

This equation has been integrated numerically by using Simpson's rule. To assess the effect of the finite street width, we compared the solutions of equation (6) for the two street emissions configurations for the case in which

$$Q = 1000 \text{ vehicles/hour}$$

$$K_c = 1 \text{ meter}^2/\text{second}$$

$$U = 1 \text{ meter/second} \quad .$$

The results, plotted as CO concentration vs. distance from street centerline, are shown in Figure 7. At a distance of 15 meters, the minimum at any of the Los Angeles monitoring stations that we considered, the discrepancy in predicted concentrations is .025 ppm at an average level of .72 ppm, or about 3.5%. This discrepancy decreases as the distance from centerline increases, becoming zero at distances in excess of 50 meters. Based on this comparison, we felt that the assumption of emissions emanating from a source of infinitesinal width is justified.

The solution of equation (6) is straightforward, but it does require the availability of a table of Bessel functions. To eliminate this need, and for that matter the need to evaluate equation (6) at all, we have computed solutions of the equation for a range of variables that commonly arise in applying the model in Los Angeles. These solutions, given in Figures 8 to 11, apply for

$$0.5 < U \text{ (meters/second)} < 4.0$$

$$0.125 < K_c \text{ (meters}^2\text{/second)} < 2.0$$

$$10 < x \text{ (meters)} < 1000$$

Note that the ordinate of these plots is given as $1000(c/N)$, where N is the number of vehicles passing per hour along a surface street.

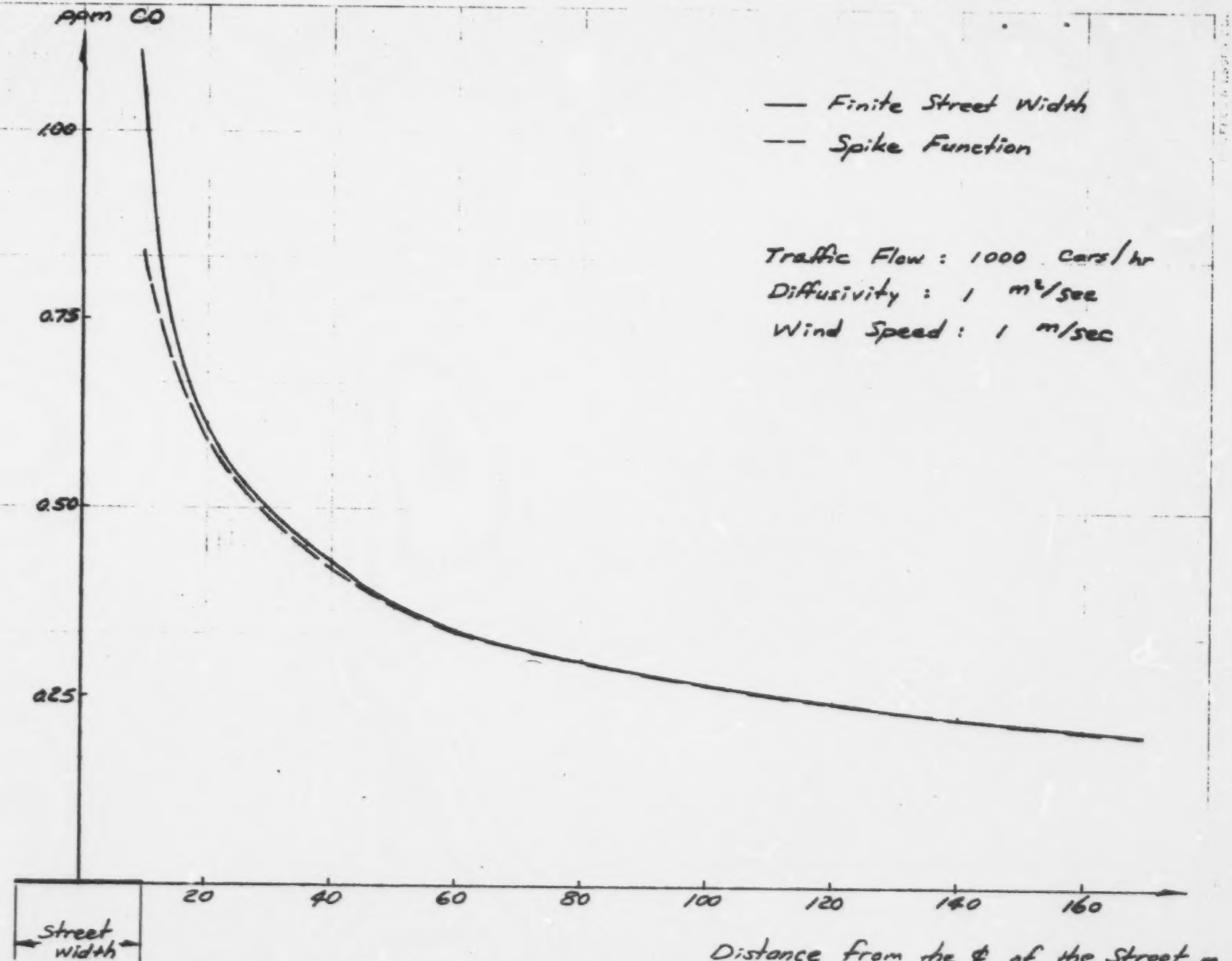


FIGURE 7. Comparison Between Solution of the Continuity Equation for Finite and Zero Street Widths

K&E SEMI LOGARITHMIC 46 4972
2 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

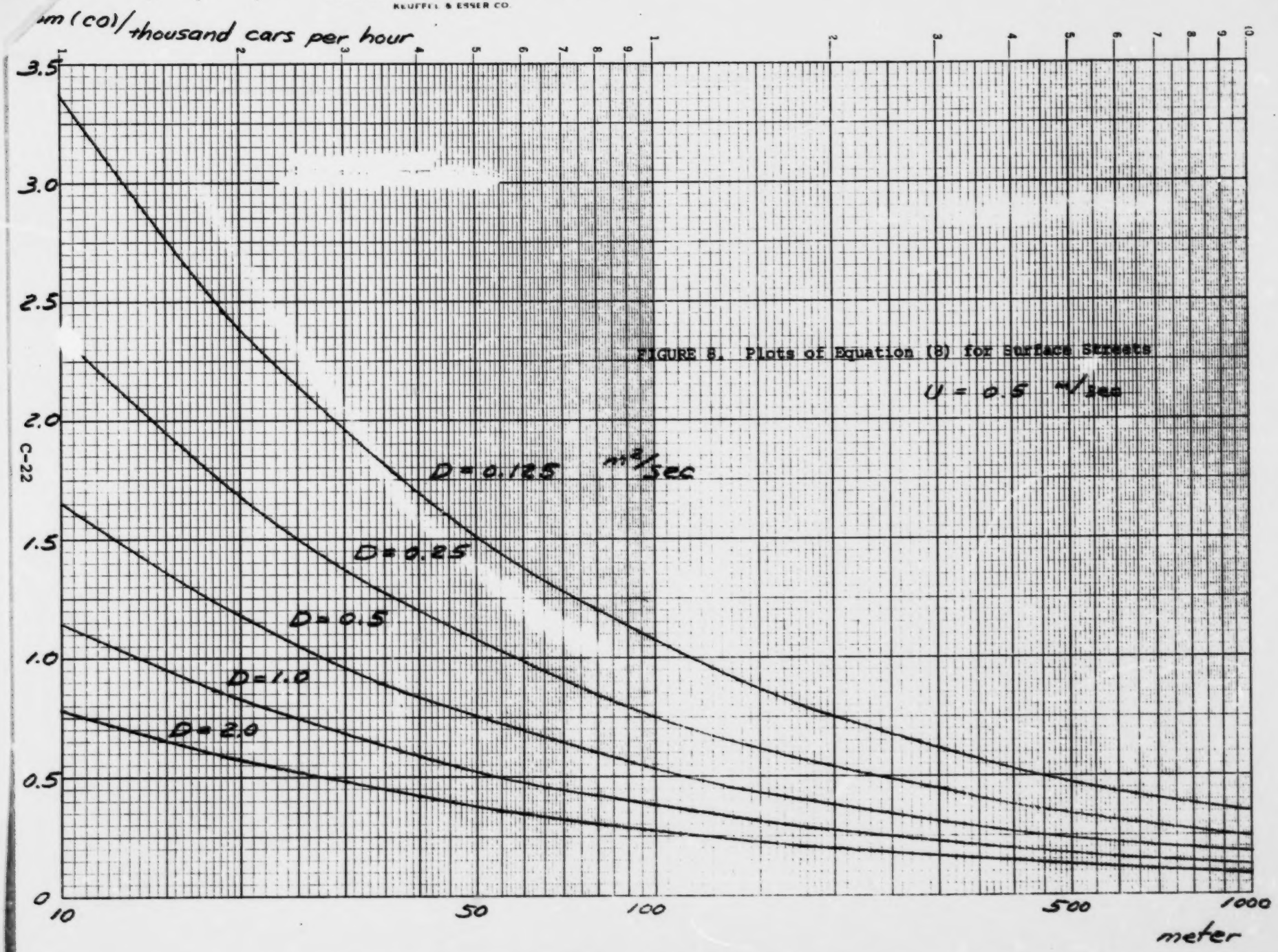


FIGURE 8. Plots of Equation (8) for Surface Streets

U = 0.5 m/sec

K·E SEMI LOGARITHMIC 46 4972
2 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

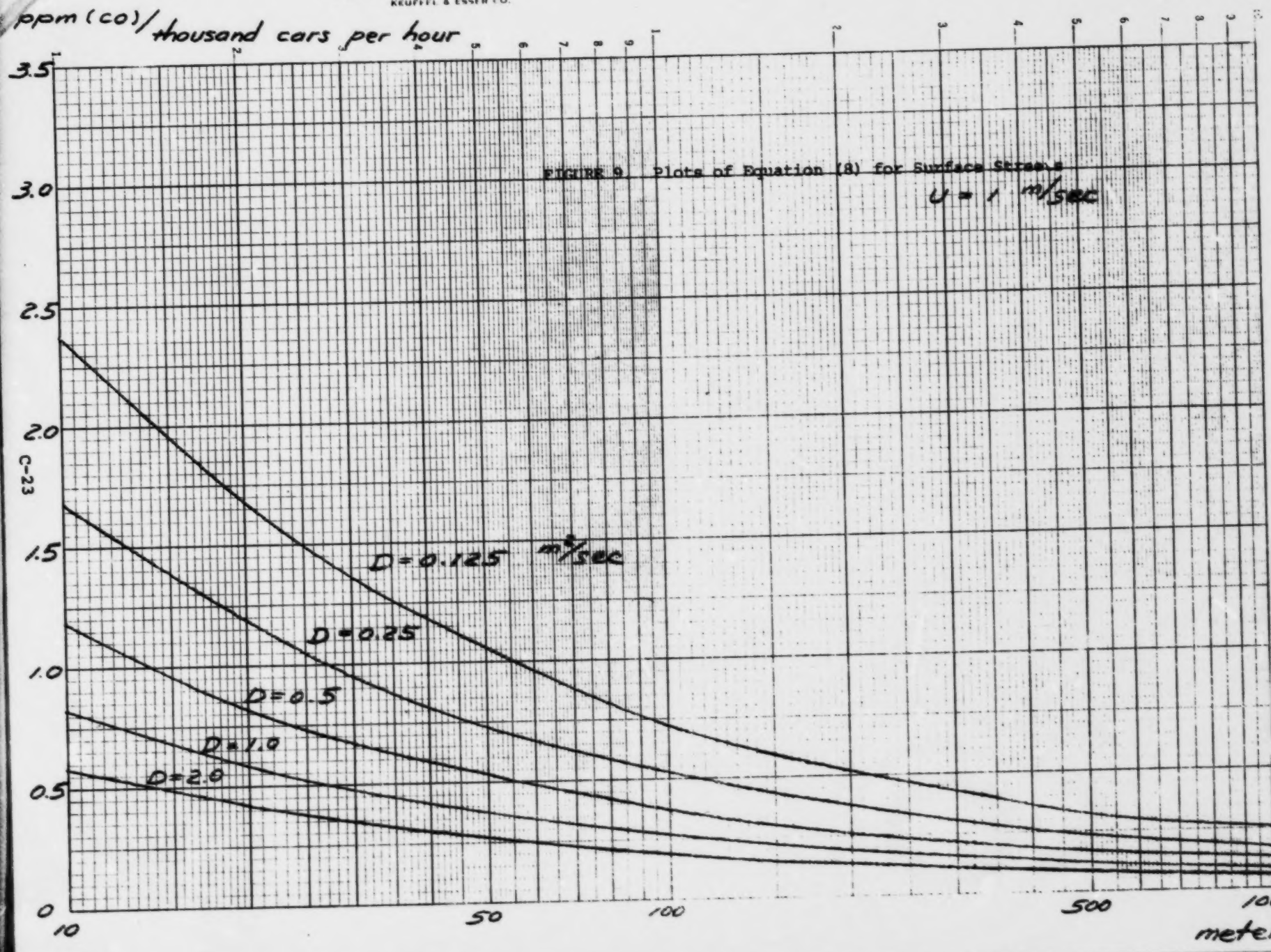


FIGURE 9. Plots of Equation (8) for Surface Streets

Reproduced from best available copy.

K&E SEMI LOGARITHMIC 46 4972
2 CYCLES X 3 DIVISIONS
KEUFFEL & ESSER CO

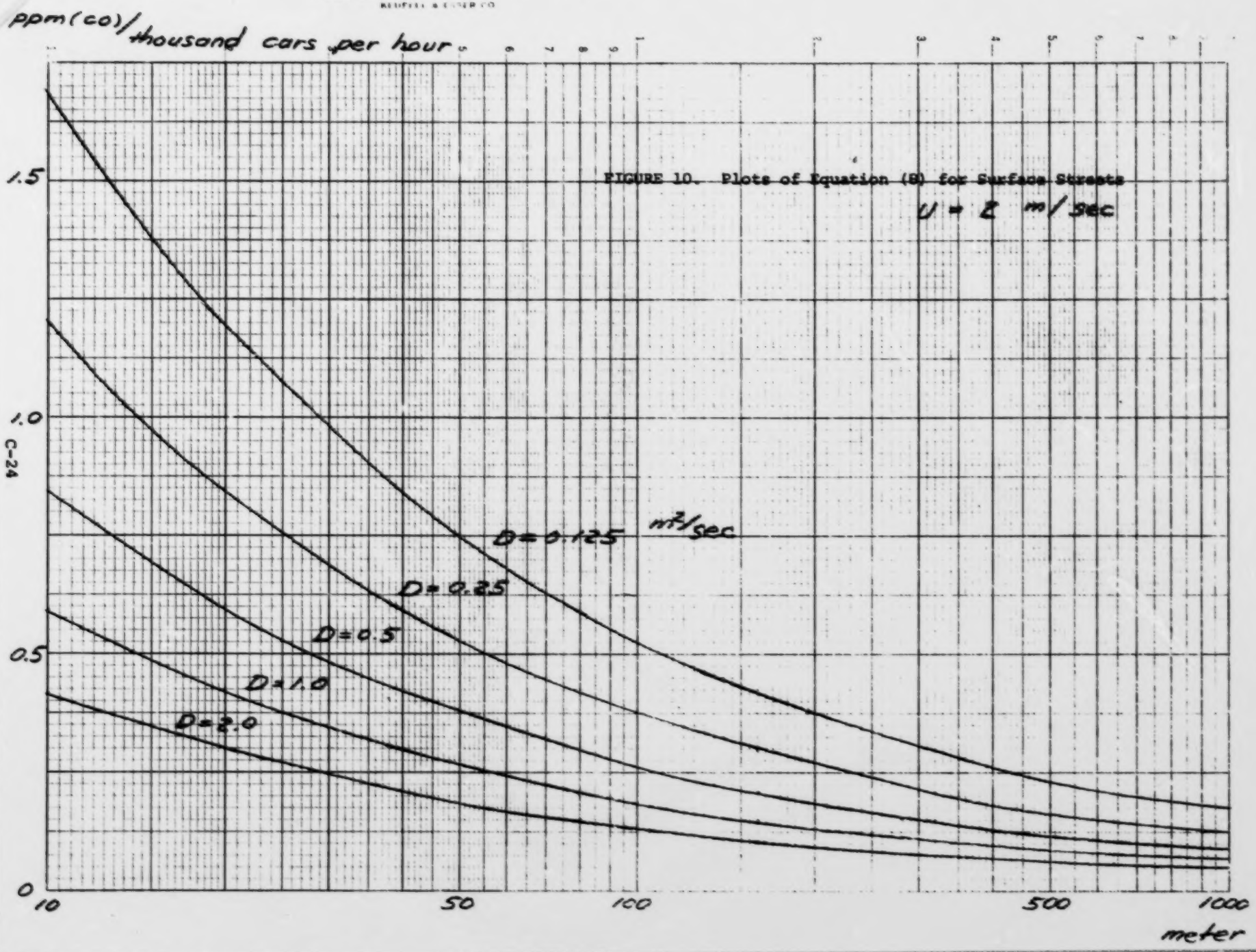


FIGURE 10. Plots of Equation (8) for Surface Streets

U = 2 m/sec

K-E SEMI LOGARITHMIC 46 4972
2 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO

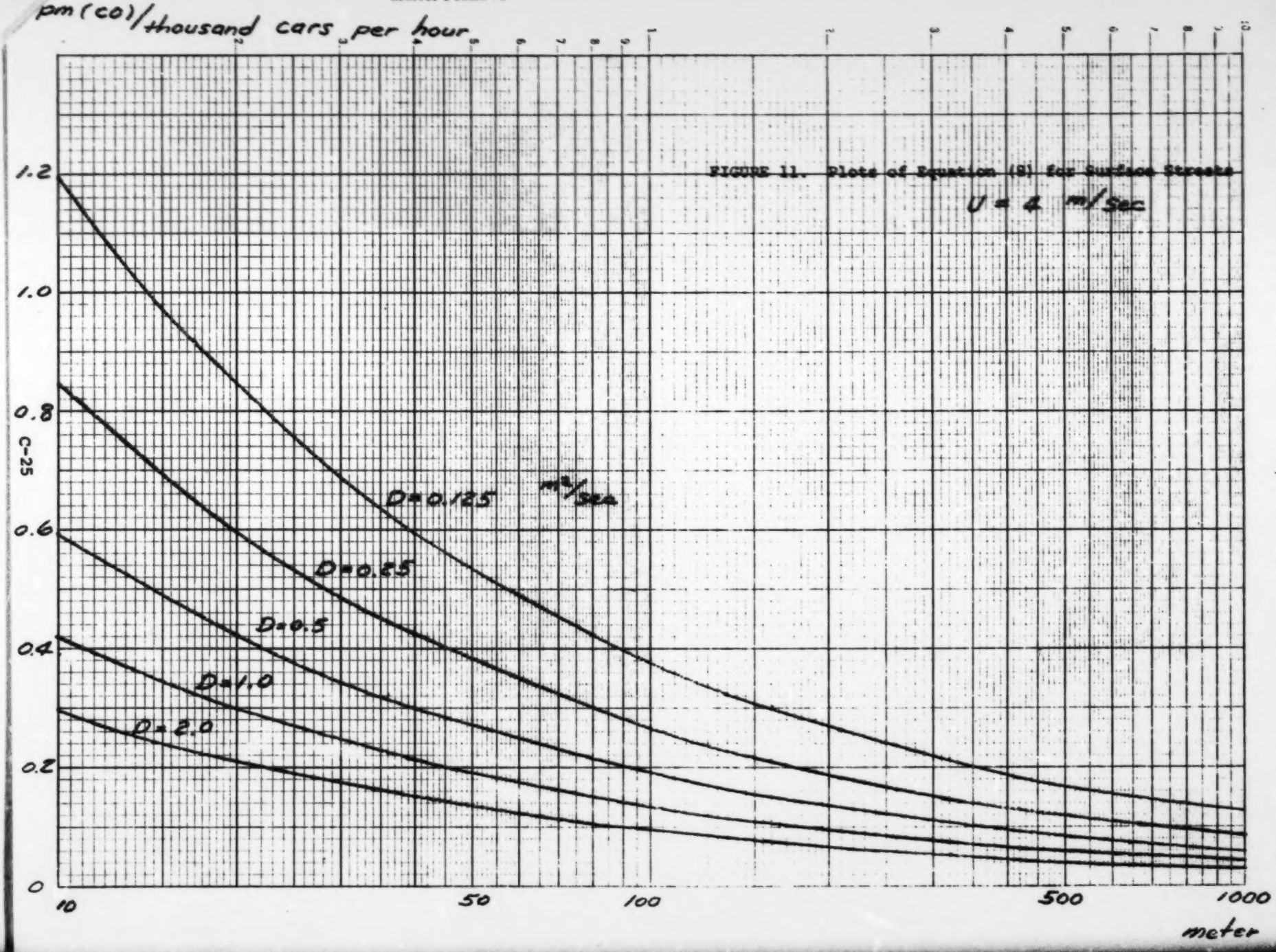


FIGURE 11. Plots of Equation (8) for Surface Streets

U = 4 m/sec

IV. RESULTS

As we have discussed earlier, the main purpose of this limited modeling effort was to investigate the feasibility of developing a simple model capable of describing local or sub-grid scale emissions and transport processes and thus their contributions to measured air quality levels. Since the scope of the effort is quite restricted, there are necessarily a number of considerations of practical importance that we have not addressed. In particular, we have limited application to

- roadway sources
- inert pollutants, in this case carbon monoxide
- the free flow regime
- a selected group of monitoring sites
- times of day when corrections are likely to be significant. The primary period of interest is between 5 A.M. and 10 A.M., when heavy traffic and light winds are common.

Fifteen monitoring stations were operative during the six "validation days" in 1969--11, 29, and 30 September, 29 and 30 October, and 4 November. Ten were operated by the LA APCD, three by the Orange County APCD, and two by Scott Research Laboratories. Of these the Orange County stations and the Pasadena station were not considered for this feasibility study because they were inoperative on several of the validation days. The mobile Scott stations were not considered, because their locations with respect to neighboring streets were unknown. Of the remaining nine stations, two (at Reseda and Azusa) are located on streets having little or no traffic, one (downtown Los Angeles) is situated along a street canyon, one (Burbank) is located in a region of complex and rapidly varying wind patterns, and one (Pomona) is located one mile outside of the modeling region. The remaining four stations--Lennox, West Los Angeles, Whittier, and Long Beach--were selected for application of the model. The locations of these stations are illustrated diagrammatically in Figures 12 to 15.

Hourly averaged carbon monoxide concentrations attributable to local roadway sources were estimated for the period 5 A.M. to 10 A.M. (local time) for each of the six validation days using the diffusivity vs. time curve of Figure 6 and the plots given in Figures 8 to 11. The estimated increases in CO concentration above background are given in Figures 16 to 33.* These increases are also shown in the plots in the main report

---

* No results are plotted for cases in which increases are negligible. These are:

Date	Station
September 11, 1969	West Los Angeles
September 11, 1969	Whittier
September 30, 1969	West Los Angeles
October 29, 1969	West Los Angeles
October 30, 1969	Long Beach
November 4, 1969	West Los Angeles

which display CO validation results for the full airshed model. Traffic counts used in these calculations were taken from average traffic statistics made available by the traffic department of the municipality in which the station is located. Wind speed and direction were measured continuously at each monitoring station, with the exception of Lennox; however, the recorder sheets were unavailable. Thus, average hourly wind statistics were used.* We are unable at present to estimate the errors that these two averaging processes introduce.

In all respects but one the calculations were based on the measured values of variables and the plots displaying the solutions of equation (6). The exception involves the use of wind statistics at low wind speeds. In perhaps four or five instances of low winds we predicted little or no local contribution to measured concentrations when, in fact, such contributions were clearly being made. We attributed this anomaly to the fact that under the prevailing calm conditions, anemometers either drift or are not displaced by the light force exerted on the vanes. In any case, the instantaneous and average hourly wind statistics are very likely poorly correlated. Thus, in instances in which high local contributions were evident but not predicted on the basis of average hourly statistics, we assumed a wind direction that maximized the local contribution to measured concentrations.* The monitoring sites, validation days, and times for which this extraordinary calculation was made are the following:

STATION	DAY	TIME	WIND SPEED	HOURLY AVERAGE WIND DIRECTION	ASSUMED WIND DIRECTION
West LA	9/29/69	5-9 A.M.	1 mph	W → SW	E
Long Beach	9/11/69	5-6 A.M.	1 mph	NW → WNW	NE
Long Beach	9/30/69	5-8 A.M.	1 mph	NE → SE	W
Whittier	9/30/69	6 A.M.	1 mph	W	NE

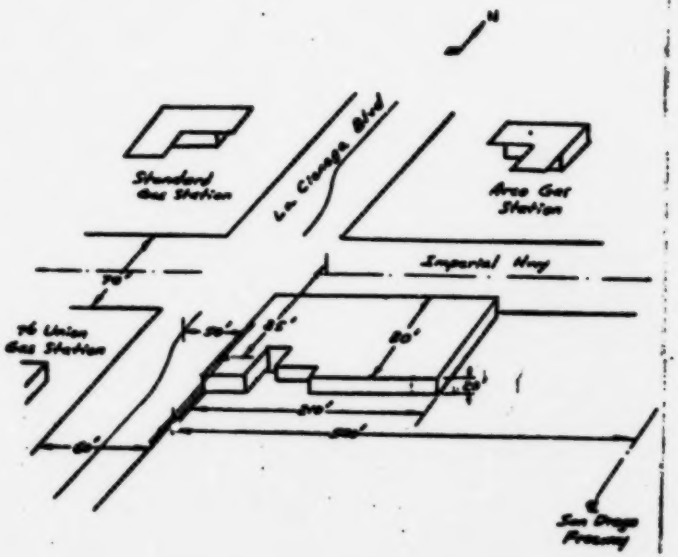
*In essence, the wind-direction dependence in the present model has been abandoned in the low-wind cases. This is in line with a comment made by Dr. Ralph Sklarew of EPA who suggested that a simple correlation of the following type be established for each station,

$$C_{observed} = C_{model} + \Delta C_{local} \quad \text{where} \quad \Delta C_{local} = \alpha \frac{Q}{U}$$

with Q and U having temporal dependence and α characterizing the station. Note that, in this relationship, predicted concentrations are independent of wind direction.

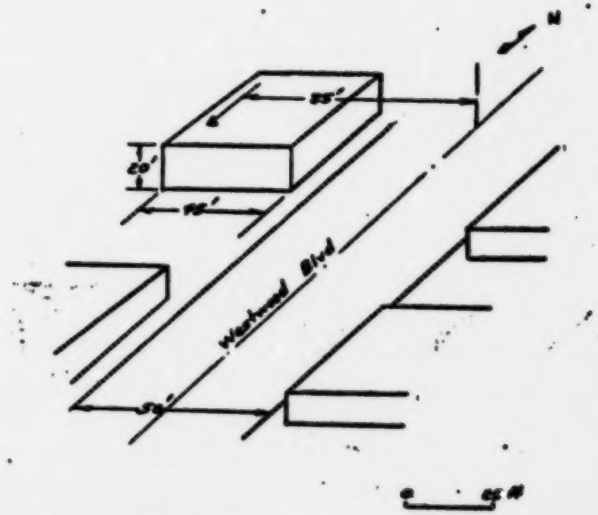
More acceptable procedures for dealing with calm conditions depend upon having access to the continuously recorded wind data.

In evaluating the results, comparisons can only be made between measured concentrations and the sum of predicted concentrations calculated using both the microscale model and the full airshed model. For this reason, evaluation of results is presented in the main text. It should suffice here to say that the results appear to be quite promising, given the restricted nature of the data. However, a full and fair evaluation must await the acquisition of a more complete data base, more suited to the temporal and spatial resolution of the microscale model. In addition, the model must be applied in a wider variety of situations. Finally, it must be extended so as to be applicable in situations involving street canyon vortex flows and reacting pollutants (notably nitrogen oxides and oxidants).



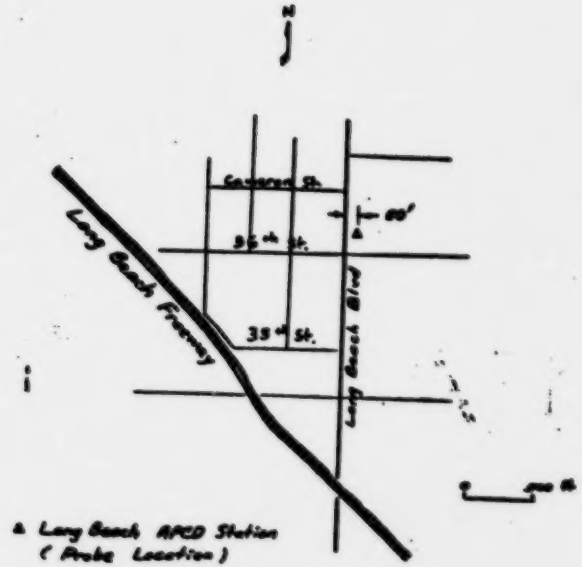
▲ Lennox APCD Station
(Probe Location)

FIGURE 12. Schematic Diagram: Lennox Station



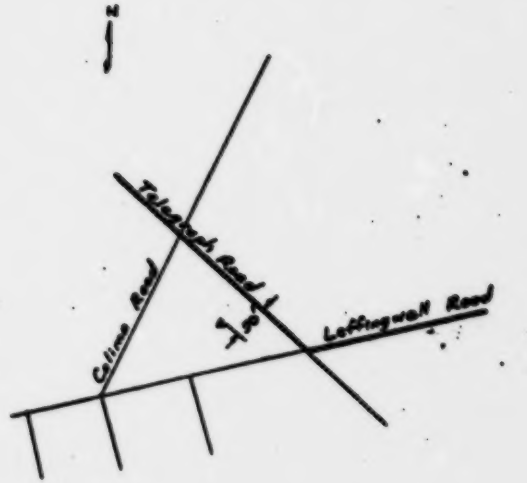
▲ West LA APCD Station
(Probe Location)

FIGURE 13. Schematic Diagram: Westwood Station



▲ Long Beach APCD Station
(Probe Location)

FIGURE 14b. Schematic Diagram Long Beach Station



▲ Whittier APCD Station
(Probe Location)

FIGURE 15. Schematic Diagram Whittier Station

FIGURE 16. Predicted Carbon Monoxide Concentrations: Lennox Station 9/11/69

Time	Wind Speed	Wind Direction	Traffic Count La Cienega	Traffic Count Imperial	Traffic Count S.D. Freeway
5	2	SSW	1600	2000	6200
6	3	SSW	2100	3600	20000
7	2	WNW	1300	2500	26000
8	4	WSW	900	1400	22000
9	5	W	900	1400	18000

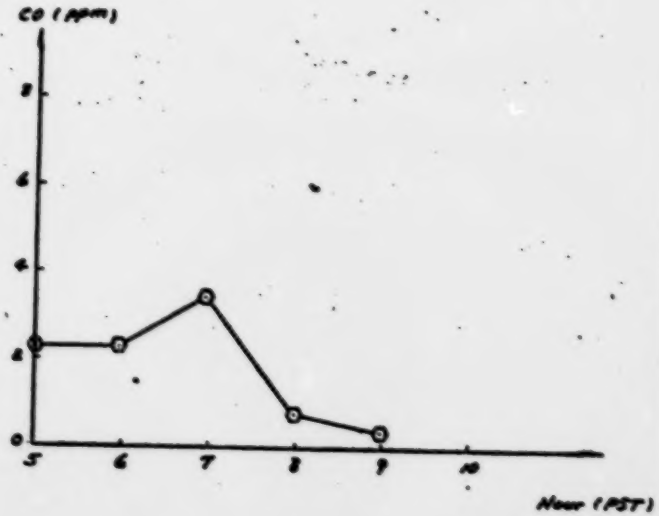


FIGURE 17. Predicted Carbon Monoxide Concentrations: Lennox Station 9/29/69

Time	Wind Speed	Wind Direction	Traffic Count La Cienega	Traffic Count Imperial	Traffic Count S.D. Freeway
5	4	W	1600	2000	6200
6	3	WNW	2100	3600	20000
7	2	NW	1300	2500	26000
8	2	WNW	900	1400	22000
9	4	WSW	900	1400	18000

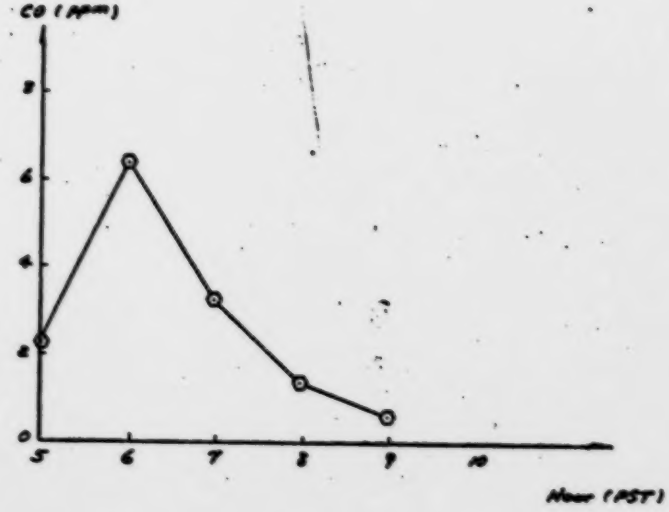


FIGURE 18. Predicted Carbon Monoxide Concentrations: Lennox Station 9/30/69

Time	Wind Speed	Wind Direction	Traffic Count La Cienega	Traffic Count Imperial	Traffic Count SD Freeway
5	3	NNE	1600	2000	6200
6	3	NNE	2100	3600	20000
7	3	WSW	1300	2500	26000
8	3	S	900	1400	22000
9	2	S	900	1400	18000

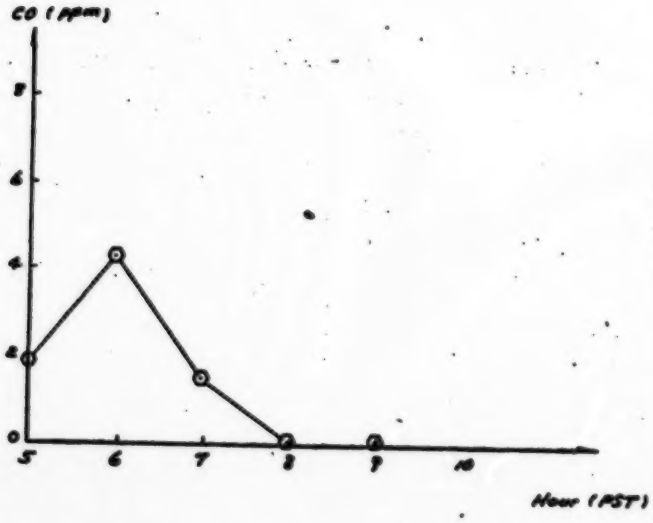


FIGURE 19. Predicted Carbon Monoxide Concentrations: Lennox Station 10/29/69

Time	Wind Speed	Wind Direction	Traffic Count La Cienega	Traffic Count Imperial	Traffic Count SD Freeway
5	4	ENE	300	350	2700
6	5	NE	1600	2000	6200
7	2	E	2100	3600	20000
8	2	WNW	1300	2500	26000
9	6	W	900	1400	22000
10	8	W	900	1400	18000

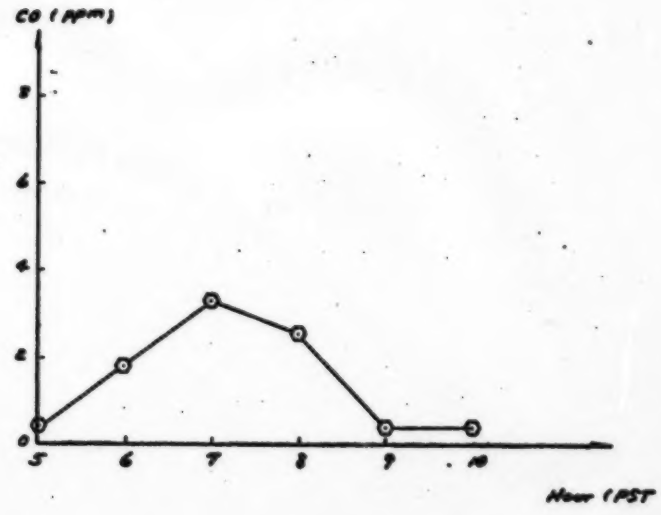


FIGURE 20. Predicted Carbon Monoxide Concentrations: Lennox Station 10/30/69

Time	Wind Speed	Wind Direction	Traffic Count La Cienega	Traffic Count Imperial	Traffic Count S.D. Freeway
5	2	ENE	300	350	2700
6	3	ENE	1600	2000	6200
7	2	NE	2100	3600	20000
8	3	N	1300	2500	26000
9	6	NNE	900	1400	22000
10	7	N	900	1400	18000

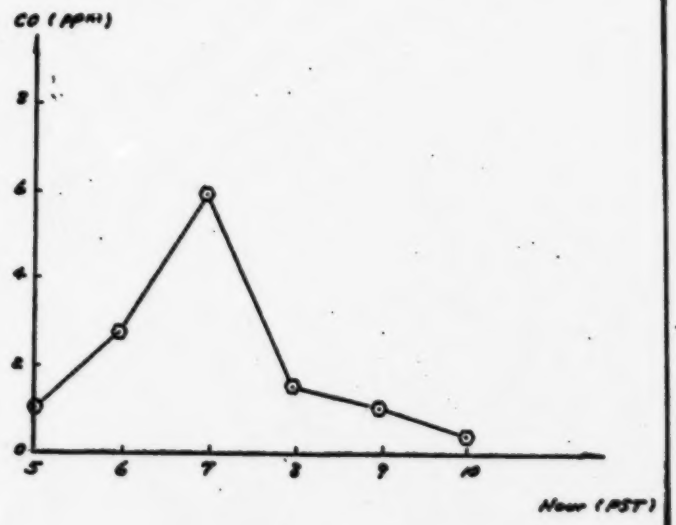


FIGURE 21. Predicted Carbon Monoxide Concentrations: Lennox Station 11/4/69

Time	Wind Speed	Wind Direction	Traffic Count La Cienega	Traffic Count Imperial	Traffic Count S.D. Freeway
5	6	WNW	300	350	2700
6	4	NW	1600	2000	6200
7	3	WNW	2100	3600	20000
8	3	W	1300	2500	26000
9	7	WSW	900	1400	22000
10	8	WSW	900	1400	18000

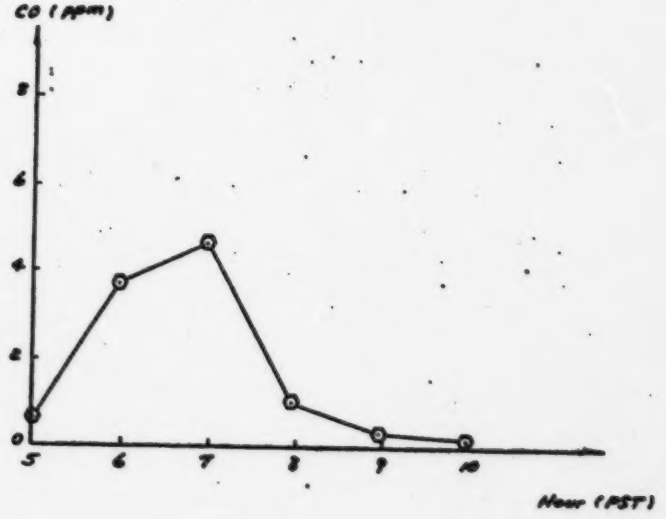


FIGURE 22. Predicted Carbon Monoxide Concentrations: West LA Station 9/29/69

Time	Wind Speed	Wind Direction	Traffic Count Westwood Blvd
5	1	E	250
6	1	E	950
7	1	E	1100
8	1	E	800
9	1	E	820

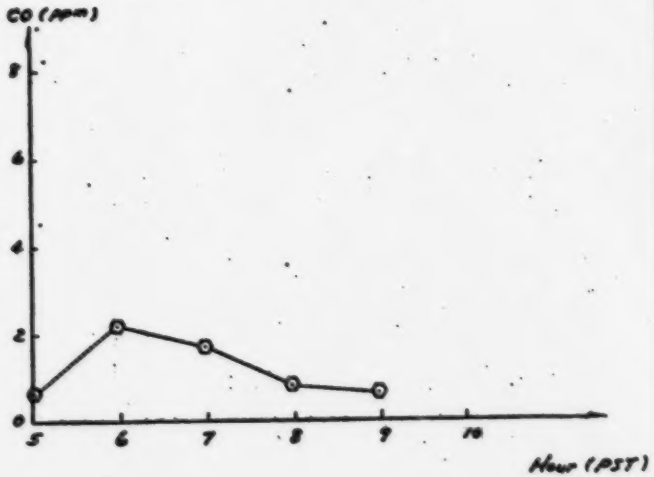
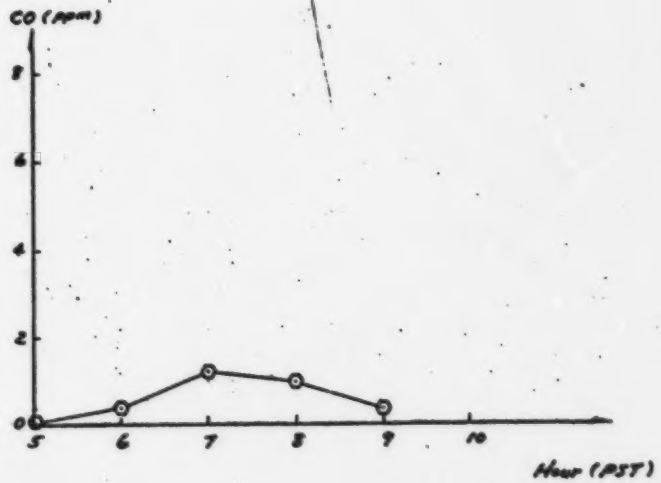


FIGURE 22. Predicted Carbon Monoxide Concentrations: West LA Station 10/30/69

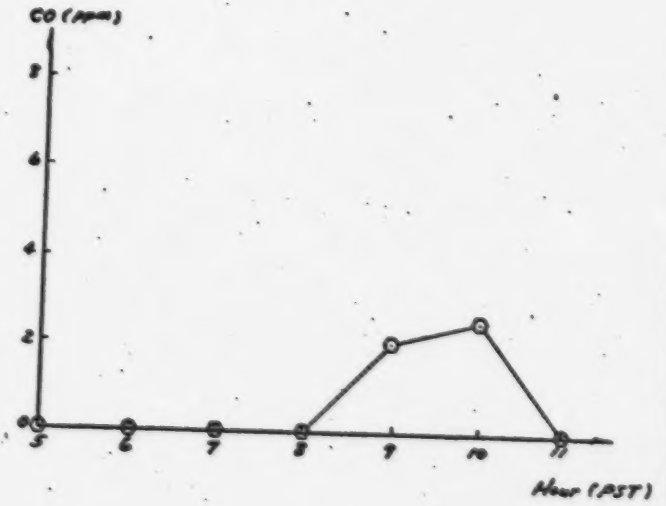
Time	Wind Speed	Wind Direction	Traffic Count Westwood Blvd
5	2	NE	100
6	1	NE	250
7	1	NE	950
8	1	NE	1100
9	1	NE	820



Long Beach Station

FIGURE 24. Predicted Carbon Monoxide Concentrations: 9/11/69

Time	Wind Speed	Wind Direction	Traffic Count Long Beach Blvd
5	1	NE	740
6	1	NE	2300
7	2	NNE	4000
8	2	NNE	3700
9	3	W	3500
10	2	WNW	3900
11	7	S	4300



Long Beach Station

FIGURE 25. Predicted Carbon Monoxide Concentrations: 9/29/69

Time	Wind Speed	Wind Direction	Traffic Count Long Beach Blvd
5	2	W	740
6	3	WNW	2300
7	2	NW	4000
8	3	W	3700
9	4	W	3500
10	7	WNW	3900
11	5	W	4300

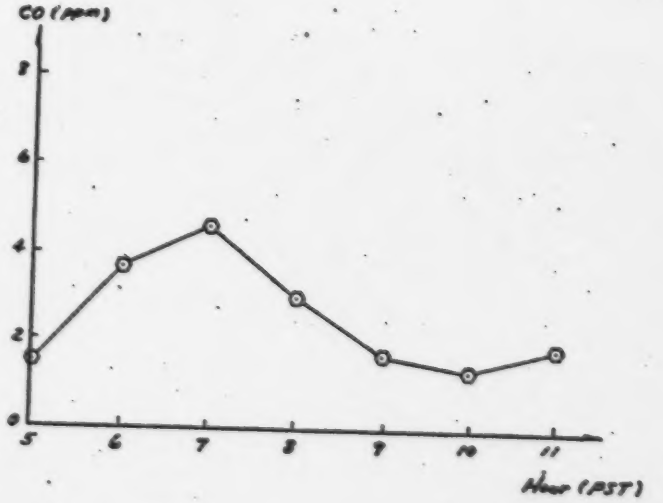


FIGURE 24. Predicted Carbon Monoxide Concentrations: Long Beach Station 9/11/69

Time	Wind Speed	Wind Direction	Traffic Count Long Beach Blvd
5	1	NE	740
6	1	NE	2300
7	2	NNE	4000
8	2	NNE	3700
9	3	W	3500
10	2	WNW	3900
11	7	S	4300

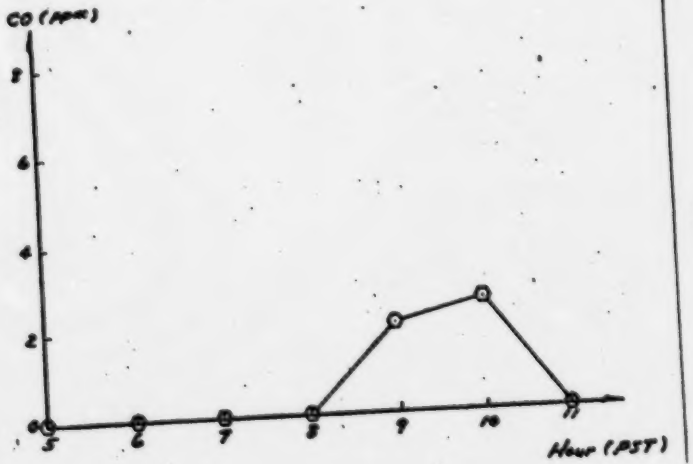
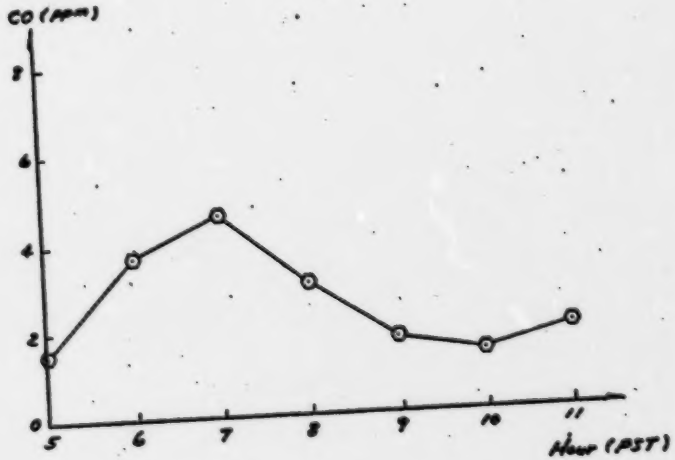


FIGURE 25. Predicted Carbon Monoxide Concentrations: Long Beach Station 9/29/69

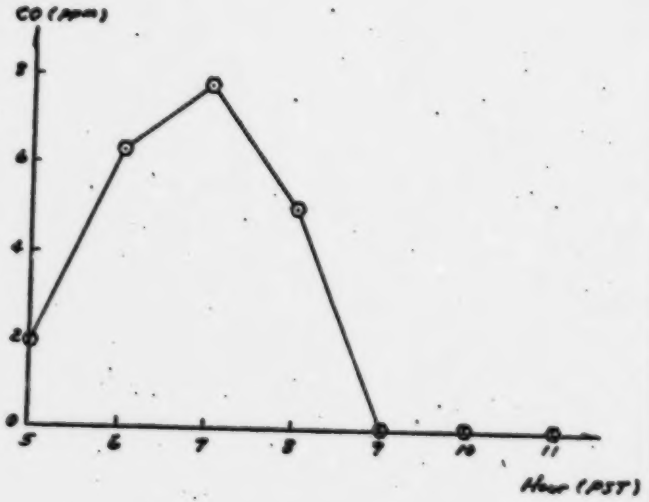
Time	Wind Speed	Wind Direction	Traffic Count Long Beach Blvd
5	2	W	740
6	3	WNW	2300
7	2	NW	4000
8	3	W	3700
9	4	W	3500
10	7	WNW	3900
11	5	W	4300



Long Beach Station

FIGURE 26. Predicted Carbon Monoxide Concentrations: 9/30/69

Time	Wind Speed	Wind Direction	Traffic Count Long Beach Blvd
5	1	W	740
6	1	W	2300
7	1	W	4000
8	1	W	3700
9	3	SE	3500
10	2	E	3900
11	7	S	4300



Long Beach Station

FIGURE 27. Predicted Carbon Monoxide Concentrations: 10/29/69

Time	Wind Speed	Wind Direction	Traffic Count Long Beach Blvd
5	1	NNE	180
6	2	NNW	740
7	3	N	2300
8	4	WNW	4000
9	3	NW	3700
10	6	W	3500
11	5	W	3900

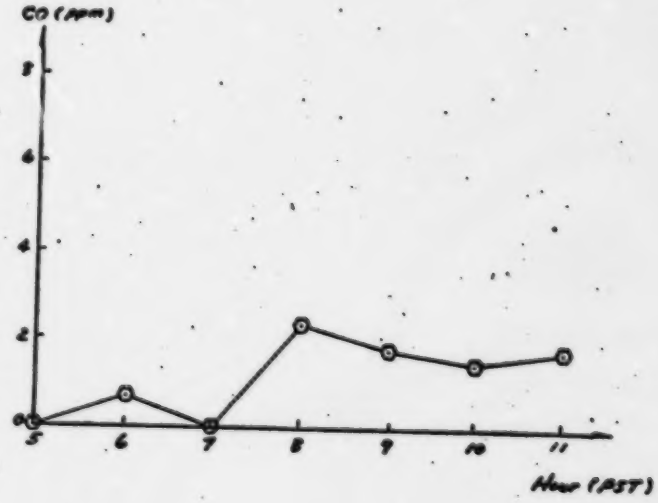


FIGURE 18. Predicted Carbon Monoxide Concentrations: Long Beach Station 11/4/69

Time	Wind Speed	Wind Direction	Traffic Count Long Beach Blvd
5	3	WNW	180
6	3	WNW	740
7	2	NE	2300
8	2	ENE	4000
9	7	W	3700
10	6	W	3500
11	4	W	3900

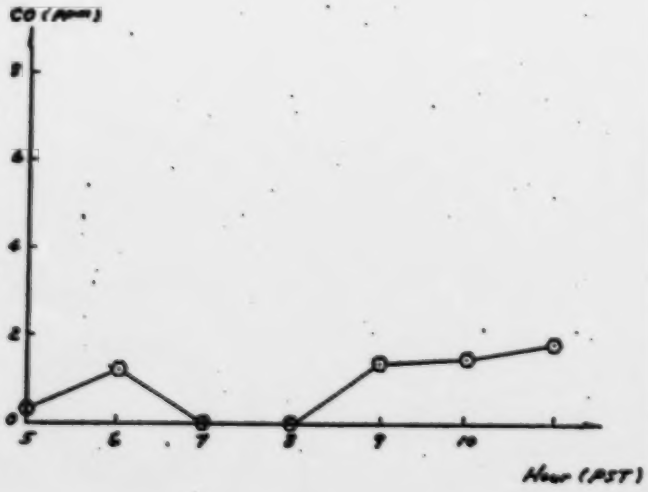


FIGURE 19. Predicted Carbon Monoxide Concentrations: Whittier Station 9/29/69

Time	Wind Speed	Wind Direction	Traffic Count Telegraph Road
5	4	WNW	1440
6	3	NNW	1700
7	4	NNW	960
8	2	WNW	680
9	2	S	750

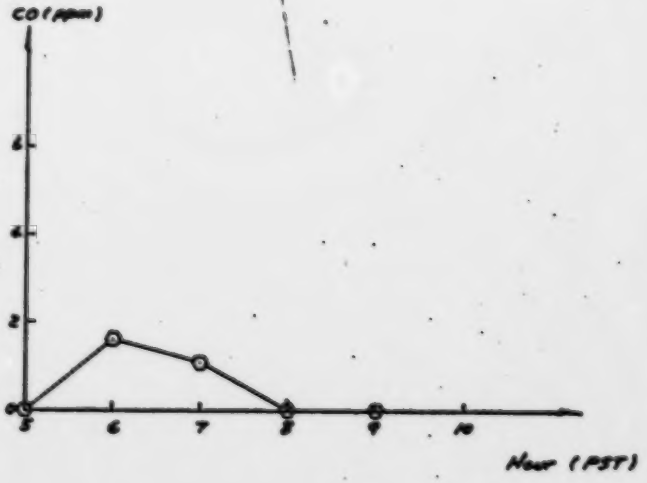


FIGURE 10. Predicted Carbon Monoxide Concentrations: Whittier Station 9/30/69

Time	Wind Speed	Wind Direction	Traffic Count Telegraph Road
5	1	E	1400
6	1	E	1760
7	2	S	940
8	2	SSE	680
9	3	SSE	750

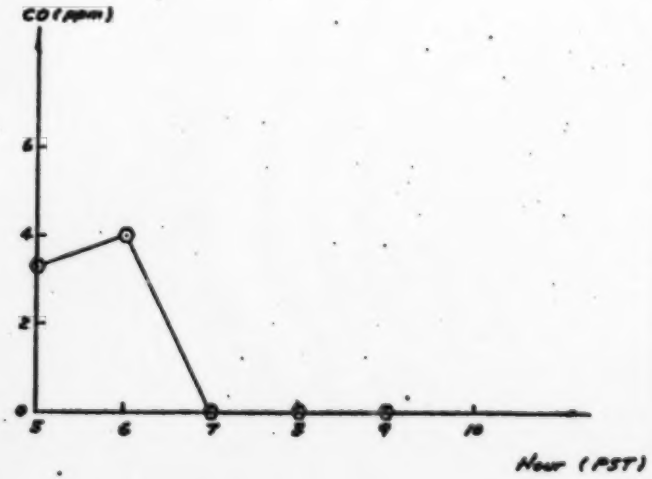
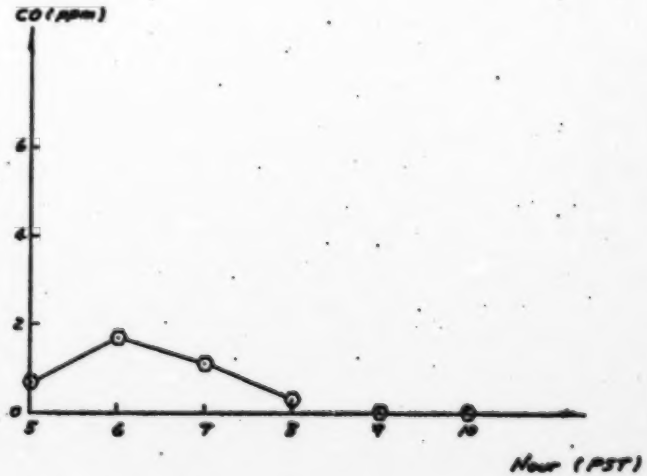


FIGURE 11. Predicted Carbon Monoxide Concentrations: Whittier Station 10/29/69

Time	Wind Speed	Wind Direction	Traffic Count Telegraph Road
5	4	N	620
6	2	NNW	1400
7	4	NNW	1760
8	7	NNW	940
9	6	WNW	680
10	3	WNW	750



V. RECOMMENDATIONS FOR FUTURE WORK

We believe that a microscale or sub-grid scale model is an essential ingredient in an urban or regional scale model, as it is not possible to adequately describe all pertinent physical phenomena at the coarser scale, or for that matter, with a model restricted to only one scale. We further believe that the feasibility of developing and applying a microscale model has been demonstrated in this study. But, because of the limited scope of this effort, the model developed constitutes only a beginning. A major second phase study is needed, the primary goal of which is the development and validation of a sub-grid scale model that is capable of predicting concentration "elevations" due to local transport, diffusion and reaction phenomena. We briefly mentioned in the last section the major objectives that such an effort should satisfy. In this section, we discuss them in more detail.

As noted, we have attempted to formulate a model only for the relatively simple case of the free flow regime. We have considered the most pertinent parameters in our formulation--the strength of the source, the wind, the dispersion coefficient and the distance between the source and the receptor. For more complicated cases where recirculating flows are set up, i.e., for cases where $\delta < W$, additional model development is needed, particularly for application in the commercial areas of large cities. Two alternative modeling approaches are envisioned--the correlation model and the physical model. The first alternative, as indicated in the previous sections, has already been developed by Georgii, et al. (1967), Georgii (1969), Schnelle, et al. (1969) and Johnson, et al. (1971). Improvements may be made by including parameters that have been omitted from these relationships thus far, such as the diffusion coefficient, the distance from the roadway, and geometric factors that characterize the street configuration. The second approach, on the other hand, involves solving a simplified form of the governing equations of continuity and momentum, probably the species continuity equation with a parameterized velocity field. However, successful development of this type of model will require the thorough study of recirculatory flows and careful formulation of the simplified equations.

An undertaking of equal importance is the expansion of modeling approaches, both for Case 1 and 2 flows, so that they are applicable for reactive pollutants. Both nitric oxide and hydrocarbons are emitted from automobiles in substantial quantities; thus, the concentrations of these species in the immediate vicinity of the roadway is high. At locations at which concentrations are elevated, atmospheric reactions can proceed quite rapidly. It is therefore important to consider reactions, as well as transport and dispersion, in phenomenological modeling.

We can envision writing equations of continuity for NO, NO_2, and O_3, including reaction terms in each, to account for the fastest reactions

$$NO_2 + h\nu \overset{1}{\rightleftharpoons} NO + O$$

$$O_2 + O + M \overset{2}{\rightleftharpoons} O_3 + M$$

$$NO + O_3 \overset{3}{\rightleftharpoons} NO_2 + O_2$$

These equations, being coupled through the reaction terms, theoretically would have to be numerically integrated to obtain solutions. However, because these reactions proceed rapidly, steady-state concentrations may be established on a time scale that is short compared with the scale of transport. If the validity of this supposition can be demonstrated, we could decouple the transport and reaction portions of the equations and solve them separately, thus considerably easing the calculational burden. However, there are many aspects to a complex physical situation such as this, and each must be carefully evaluated before a particular modeling approach can be adopted.

To properly validate a local model, it is most important to have available a data base collected for the specific purpose of filling this role. In order to distinguish between local and background contributions to air quality at a particular location, pollutant concentrations should be measured on a temporary basis upwind of the monitoring or test site. In addition, we would wish to have available continuous recordings of wind speed and direction and pollutant concentration. The data could then be averaged over varying periods of time--say from one minute to one hour--and the model tested in order to establish both appropriate averaging periods and the effects of selecting averaging periods that are too long. Finally, turbulence measurements would be most helpful in obtaining improved estimates of K_c and its variation in time during the morning hours following sunrise.

A final requirement, perhaps one that ought to be satisfied first, is that of a fuller evaluation of the present model using data that are readily available. For it may be some time until a more suitable data base becomes available for this use. The model might be applied at those

monitoring sites that have not been considered for application thus far (with the exception, of course, of the downtown station). When sites are near busy intersections, in the vicinity of a freeway and major arterials (and on/off ramps), or near a service station, the effects of all possible sources should be evaluated. Since we are concerned heavily with the early hours of the day in assessing local effects, attention should be given to the treatment of vehicle emissions rates in terms of degree of congestion, frequency with which vehicles are stopped at red lights near the intake port of the station (and thus, in the idle mode), estimated fraction of vehicles that are cold and hot running, and other sources of variation in emissions.

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